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The water vapour conductance of *Eucalyptus* litter layers

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Abstract

Forest litter layers modify the exchange of water vapour between the soil and atmosphere below the forest canopy. Water vapour fluxes are determined by the conductance of the litter layer, a parameter which has not previously been measured for *Eucalyptus* litter layers. In this study, the water vapour conductance of *Eucalyptus globulus* litter layers was examined in the laboratory to provide an observational basis for a model of vertical water vapour transfer in a litter layer. Conductance was measured for four different types of litter layers: 25 and 50-mm thick layers of leaves, a 25-mm layer of compressed leaves, and a 25-mm layer of partially decomposed litter. In addition, the vertical variation of conductance in a 50-mm thick leaf layer was examined. Without wind, the conductance of all four layers was 50–75% less than the measured conductance of a layer of air of the same depth. Conductance increased with increasing wind speed, from 0.5–1 mm s^{-1} without wind to 7.5–9.5 mm s^{-1} with a 3.3 m s^{-1} wind. The ratio of conductance in the top half to conductance in the bottom half of the litter layer increased from 1.3 without wind to 65 with a 3.3 m s^{-1} wind above the litter layer. This is the first time the dependence of conductance with depth on wind speed has been measured in leaf litter and may have important implications for future model development.

Keywords: Water vapour transfer; Forest litter; *Eucalyptus globulus*; Atmometer

1. Introduction

The forest litter layer consists of leaves, bark, and twigs cast from trees and understory shrubs. This layer forms a porous barrier between the soil and the canopy airflow. It intercepts radiation and precipitation, modifies heat and water vapour fluxes at the soil surface and may be a significant store and source of water vapour (Ogée and Brunet, 2002).

Understanding physical processes in the litter layer is thus of interest when constructing models of forest hydrology, where the presence of litter has an effect on soil moisture (e.g., Ogée and Brunet, 2002; Paul et al., 2003), and for bushfire studies, where the moisture content of the litter layer determines fire behaviour (Luke and McArthur, 1978), requiring predictive models of litter moisture content.

Water may be present in the litter layer in three forms: as water held in the litter solids, as free water on the litter surfaces, and as water vapour in the layer air spaces. In current models of forest litter layers (Ogée and Brunet, 2002; Paul et al., 2003), the moisture content of the litter layer is represented as a single bulk value, while evaporation from the litter layer has been described by a moisture-dependent bulk resistance (Schaap and Bouten, 1997). This bulk approach to the litter water balance is inadequate for modelling litter moisture content for fire behaviour prediction, as it does not allow: (1) representation of absorption and desorption of water vapour by the litter in response to changing relative humidity (Luke and McArthur, 1978), (2) the distinction between evaporation of free

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water from litter surfaces and from within the litter, or (3) the separation of the moisture content of the surface of the layer from that of the entire layer.

A more detailed model in which the three reservoirs of water are represented separately requires the characterisation of five processes to describe water fluxes in the litter layer: (1) vapour exchange between the litter solids and litter layer airspaces, (2) interception of precipitation by the litter, (3) condensation and evaporation of free water at the litter surfaces, (4) absorption of free water by the litter, and (5) vertical transfer of water vapour through the litter layer.

Measurements of vapour exchange (King and Linton, 1963), interception (Putuhena and Cordery, 1996), condensation (Viney and Hatton, 1990), and liquid water absorption (Simard, 1968) have been made for litter, while evaporation may be treated by standard theories for evaporation from plane surfaces (Monteith, 1973). Vertical transfer of water vapour has not been investigated in forest litter and it is that process that this paper investigates using laboratory measurements in *Eucalyptus globulus* litter layers. The aim of this paper is to make measurements that will provide an experimental basis for the development of parameterisations of the vertical transfer of water vapour in a model of litter layer moisture.

2. Review of literature

While this is the first study of this type using forest litter, several studies have measured vertical water vapour transfer in corn and straw mulch layers (Hanks and Woodruff, 1958; Gusev and Busarova, 1996; Kimball and Lemon, 1971; Novak et al., 2000; Tanner and Shen, 1990). Transfer of water vapour through the whole litter layer, between different levels within the litter layer, and between the litter layer and canopy airflow may be described using a flux-gradient equation (Tanner and Shen, 1990):

$$E = K\frac{e_{\text{top}} - e_{\text{bottom}}}{RT} \tag{1}$$

where E is the water vapour flux (kg m^{-2} s^{-1}), K the vapour conductance (m s^{-1}), R the specific gas constant for water vapour (461.5 Pa m^3 kg^{-1} K^{-1}), T the mean absolute temperature (K) of the layer, and e_{top} and e_{bottom} are vapour pressure (Pa) at the top and bottom of the layer. In Eq. (1), the water vapour conductance, K, of the layer characterises the rate at which water vapour moves through the air spaces in the litter due to a vapour pressure gradient across the layer. K depends on the structure of the litter layer and on the response of airflow within the litter layer to wind at the surface of the layer. In still air, transfer of water vapour is by molecular diffusion. With a forcing wind at the top of the litter layer, turbulent eddies develop within the litter layer and turbulent mixing dominates water vapour transfer.

The mulch layers investigated had bulk densities from 10 to 40 kg m^{-3} and ratios of solid volume to air volume of 3–12%, making them similar in structure to a *Eucalyptus* litter layer. Thus, the results of these studies provide a useful point of reference to place the *Eucalyptus* litter layer results in context. In each case, mulch layer conductance increased linearly with wind speed and could be described by a model of the form:

$$K = K_0(1 + AU) \tag{2}$$

where U is the wind speed above the mulch (m s^{-1}) at 10 cm height (measurements made at other heights have been adjusted to 10 cm height), A the constant (s m^{-1}), and K_0 is the conductance in the absence of wind (mm s^{-1}), either measured or in some cases assumed to be the conductance of a layer of still air, K_{vm}:

$$K_{\text{vm}} = \frac{D_{\text{vm}}}{d} \tag{3}$$

where D_{vm} is the molecular diffusivity of water vapour in air at 20 °C, 24.5 mm^2 s^{-1} (Massman, 1998), and d is the layer depth (mm).

Hanks and Woodruff (1958) measured the conductance of wheat straw samples 45 mm in diameter and of varying thickness in a wind tunnel. They presented their results as ratios of measured to molecular conductance, which can be reduced to give A of 0.23, 0.16, 0.14, and 0.27 for layers 6, 13, 25, and 38-mm thick, respectively. These values of A were much smaller than those of the other mulches and did not show a consistent trend with layer thickness. Kimball and Lemon (1971) measured the flux of heptane through a 20-mm thick straw mulch layer. Although they did not report conductance values, their results may be reduced to give $K_0 = 0.8$ mm s^{-1} and $A = 0.84$. Tanner and Shen (1990) measured the water vapour conductance of an 11-mm thick layer of corn residue in a wind tunnel and in the field. They measured $K_0 = 2.2$ mm s^{-1}, the same as the molecular conductance of 11 mm of air, and $A = 1.2$. Examining straw mulch layers with thicknesses of between 20 and 80 mm, Gusev and Busarova (1996) observed $K_0 = 18/d$ mm s^{-1} and $A = 2.11$. Gusev and Busarova's formula predicts $K_0 = 1.6$ mm s^{-1} for an 11-mm think layer, smaller than that observed by Tanner